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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : GOK 7/02, 15/00	A1	(11) International Publication Number: **WO 96/39617**
		(43) International Publication Date: 12 December 1996 (12.12.96)

(21) International Application Number: PCT/US96/08839

(22) International Filing Date: 4 June 1996 (04.06.96)

(30) Priority Data:
08/465,684 6 June 1995 (06.06.95) US

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(81) Designated States: BR, CA, CN, JP, SG, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: OPEN SENSOR DIAGNOSTIC SYSTEM FOR TEMPERATURE TRANSMITTER IN A PROCESS CONTROL SYSTEM
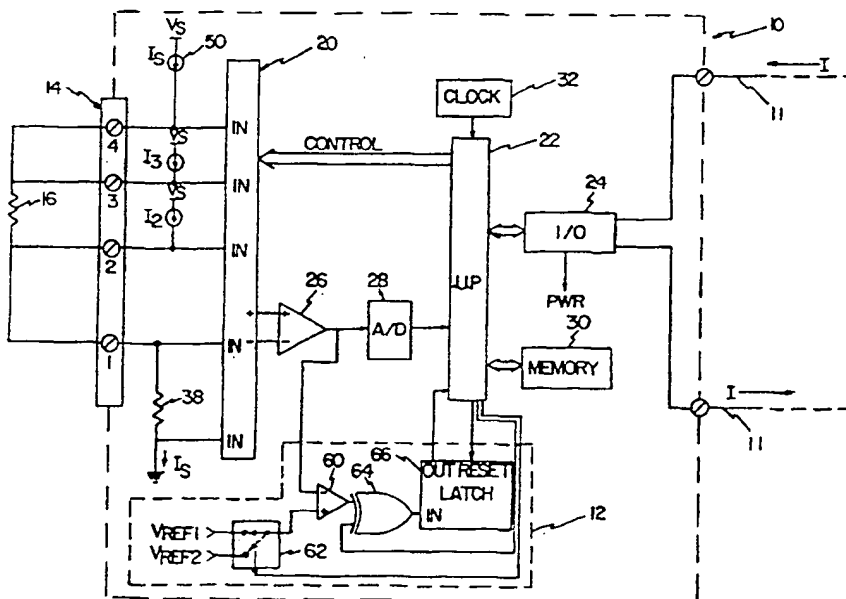
(57) Abstract

A temperature transmitter (10) in a process control system includes a temperature sensor (16, 18) which senses temperature and provides a sensor output related to sensed temperature. An analog-to-digital converter (28) coupled to the sensor output provides a digitized output related to the sensor output. A microprocessor (22) receives the digitized output, compensates the digitized output and provides a temperature output. Comparison circuitry (12) compares the sensor output to a first threshold V_{REF1} and provides an inhibit signal to the microprocessor (22) if the sensor is outside of the first threshold V_{REF1}.

OPEN SENSOR DIAGNOSTIC SYSTEM FOR
TEMPERATURE TRANSMITTER IN A
PROCESS CONTROL SYSTEM

BACKGROUND OF THE INVENTION

5   The present invention relates to transmitters used in process control systems. More specifically, the present invention relates to a diagnostic technique for identifying an open sensor condition in a temperature transmitter.

10   Process control transmitters are used to measure process parameters in a process control system. Microprocessor-based transmitters include a sensor, an analog-to-digital converter for converting an output from a sensor into a digital format, a microprocessor

15   for compensating the digitized output and an output circuit for transmitting the compensated output. Typically, this transmission is over a process control loop, such as a 4-20 mA current loop. One example parameter is temperature which is sensed by measuring

20   the resistance of an RTD (Resistive Temperature Device), also called a PRT (Platinum Resistance Thermometer) sensor, or a voltage output of a thermocouple sensor.

         Temperature is measured by converting the sensor output (resistance or voltage) to an output

25   indicative of temperature of the sensor. However, one problem occurs when there is a loose connection between the sensor and the input to the transmitter. The number of sampling periods of the analog-to-digital conversion is finite, and an intermittent open circuit can occur

30   during any of the sampling periods which is averaged out over the rest of the sampling periods, an intermittent connection can be hidden within a sampling period. Thus, the system software cannot reliably detect an

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intermittent sensor connection. Any connection which is open for a duration which is less than the sampling period may go undetected by the microprocessor and lead to inaccurate temperature readings.

5   SUMMARY OF THE INVENTION

A temperature transmitter in a process control system includes a temperature sensor providing a sensor output related to a sensed temperature and an analog-to-digital converter coupled to the sensor output. The

10   analog-to-digital converter provides a digitized output related to the sensor output. A microprocessor coupled to the digitized output compensates the digitized output and provides a temperature output. Comparison circuitry compares the sensor output to a first threshold and

15   provides an inhibit signal to the microprocessor if the sensor output is outside of the first threshold. In one embodiment, the microprocessor recognizes the inhibit signal as a fault and provides a warning output. A second threshold can be used and the comparison

20   circuitry determines whether the sensor output is within the boundaries of the first and second thresholds. The response time of the comparison circuitry is faster than the response time of the analog-to-digital converter.

                     BRIEF DESCRIPTION OF THE DRAWINGS

25   Figure 1A is a block diagram of a temperature transmitter connected to measure temperature with an RTD sensor, in accordance with one embodiment.

Figure 1B is a block diagram, like Figure 1A, of a temperature transmitter connected to measure

30   temperature with a thermocouple sensor.

Figure 2 is a flow chart showing steps performed by a microprocessor in accordance with one embodiment of the invention.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1A is a block diagram of temperature transmitter 10 connected to measure temperature with an RTD sensor. Temperature transmitter 10 includes open

5   sensor diagnostic circuitry 12, in accordance with the invention. As described below, circuitry 12 monitors the temperature sensor of transmitter 10 and provides an output upon detection of an open sensor condition. Circuitry 12 is capable of detecting a momentary open

10   circuit condition having a duration which would typically not be detectable by transmitter 10. This information is used by transmitter 10 to diagnose an open circuit condition. For example, a temperature measurement obtained by transmitter 10 in which there is

15   a momentary open circuit can be ignored to avoid inaccurate temperature measurements.

Transmitter 10 couples to process control loop 11 which provides power to transmitter 10 and over which information is transmitted and received. Transmitter 10

20   includes terminal block 14 having terminals 1 through 4 for coupling to, for example, an RTD temperature sensor 16 or a thermocouple temperature sensor 18 (shown in Figure 1B). Figure 1A shows the electrical connections to RTD 16. Sensor 16 (and sensor 18) can be either

25   internal or external to transmitter 10. Transmitter 10 includes multiplexer 20 controlled by microprocessor 22 which is coupled to control loop 11 through input/output (I/O) circuitry 24. Multiplexer 20 multiplexes appropriate sets of analog signals, including signals

30   from terminals 1 through 4, to positive and negative inputs of differential amplifier 26, which connects to high accuracy A/D converter 28. In one embodiment, converter 28 has an accuracy of 17 bits and a conversion rate of 14 samples/second. Memory 30 stores

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instructions and information for microprocessor 22,
which operates at a speed determined by clock 32.
Multiplexer 20 selectively connects input pairs to the
positive and negative inputs of differential amplifier
5   26.   A reference resistance R_{REF} 38 couples to
multiplexer 20 and is connected in series with RTD 16.

    In operation, transmitter 10 measures
temperature of sensor 16 and transmits a representation
of temperature over control loop 11. Transmitter 10
10   employs the following equation to compute the major
value of temperature of RTD 16:

$$R_{INPUT} = \frac{V_{R INPUT}}{V_{RREF}} (R_{REFNOM}) \qquad \text{Equation 1}$$

15   where:

    R_{REFNOM} =   the nominal resistance of the reference
                        resistance in ohms, and/or stored in
                        memory 30;

    $V_{R INPUT}$ =   voltage drop across the input; and
20   V_{RREF} =   voltage drop across R_{REF}.
Current source 50 provides current I_S through sensor 16
(via terminals 1 and 4) and reference resistor 38.
Microprocessor 22 measures the voltage drop ($V_{R INPUT}$)
across RTD 16 between terminals 2 and 3, and the voltage
25   drop (V_{RREF}) across resistor 38 with MUX 20. R_{REFNOM} is a
calculation constant and is retrieved from memory 30.
In a four-wire resistance measurement such as this, the
voltage drop across the connections to terminals 2 and
3 is largely eliminated, since substantially all the
30   current flows between terminals 1 and 4, and has little
impact on the accuracy of the measurement. R_{INPUT} is
converted to temperature units with a look-up table or
suitable equation stored in memory 30.

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Figure 1B shows transmitter 10 connected to measure temperature with thermocouple sensor 18 which creates a voltage $V_{TCINPUT}$ across terminals 1 and 2. Multiplexer 20 couples inputs of differential amplifier

5   26 to terminals 2 and 1.   Figure 1B shows a voltage reference (V_{TCREF}) 36 coupled to MUX 20 and current source 50.

Transmitter 10 measures the temperature of thermocouple sensor 18 by determining the thermocouple

10   voltage V_{TC} with the following equation:

$$V_{TC} = \frac{V_{TCINPUT}}{V_{TCREF}} (V_{TCREFNOM}) \qquad \text{Equation 2}$$

where:

15    $V_{TCINPUT}$ =   the measured voltage across terminals 1 and 2 of terminal block 14 sensed by amplifier 26;

V_{TCREF} =   the measured voltage generated by voltage reference 36 as sensed by

20   amplifier 26;

$V_{TCREFNOM}$ =   a nominal value of voltage reference 36 stored in memory 30;

However, the junction between two dissimilar metals formed at terminal 1 introduces a cold junction

25   error voltage proportional to the temperature of the junction. The error voltage is sensed by measuring the temperature of the junction at terminal 1 based upon the resistance of a PRT (Platinum Resistance Thermometer) sensor 34 and subsequently using a standard equation or

30   look-up table to determine the cold junction error voltage.   Resistance R_{CJCPRT} of sensor 34 is measured using Equation 1 by applying a current I_s from with current source 50.   Microprocessor 20 computes V_{TC} according to Equation 2, then effectively subtracts

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R_{CJCPRT} from V_{TC} using an appropriate look-up table or equation. Then the resulting compensated temperature of sensor 18 is coupled to loop 11 via output circuitry 24.

In the embodiments of Figures 1A and 1B, open
5   sensor diagnostic circuitry 12 and current sources I_s, I_2 and I_3 in accordance with the invention are shown. Open sensor diagnostic circuitry 12 includes comparator 60 having an inverting input coupled to the output of differential amplifier 26 or to the outputs of
10 multiplexer 20, and a non-inverting input coupled to switch 62. Switch 62 selectively couples the non-inverting input of comparator 60 to voltage reference V_{REF1} or V_{REF2} under control of microprocessor 22. The output of comparator 60 is provided to exclusive OR
15 (XOR) gate 64. A second input to exclusive OR gate 64 is provided by microprocessor 22. The output of exclusive OR gate 64 is provided to an input of latch 66. Latch 66 also includes a reset input connected to microprocessor 22 and an output connected to
20 microprocessor 22.

In operation, an open sensor condition will cause the output of amplifier 26 or the output of multiplexer 20 to go outside of its normal operating range due to current applied from current sources I_2 or
25 I_3, either too high or too low. The direction of the output variance depends upon the configuration of the input circuitry as connected through multiplexer 20. Sources I_2 and I_3 may be, for example, pull-up or pull-down resistors. Microprocessor 22 controls the
30 connection between V_{REF1} and V_{REF2} and comparator 60. Further, microprocessor 22 can invert the output of comparator 60 using exclusive OR gate 64.

Depending upon the type of reading being taken through multiplexer 20 and the direction of current

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sources I_s, I_2 and I_3, microprocessor 22 is programmed to recognize a reading which is outside of a normal operating range. For example, in Equation 1 microprocessor 22 can monitor the measurements V_{RINPUT} or

5   V_{RREF}. Similarly, microprocessor 22 can monitor the voltage across sensor terminals 1 and 2 to sense if sensor lead 2 is open, or can monitor voltage across sensor terminals 1 and 3 to sense if sensor lead 3 is open. Similarly, microprocessor 22 can monitor $V_{TCINPUT}$

10 or V_{TCREF}. For example, if, for any one sensor lead, an open connection would cause the output of amplifier 26 to go above a normal operating range, microprocessor 22 operates switch 62 to connect the appropriate reference level to comparator 60. This would result in a sensor

15 open circuit condition causing the output of comparator 60 to go to a logic LOW. In one embodiment, the input to exclusive OR gate 64 is set so that the exclusive OR gate inverts the signal to a HIGH level to signal microprocessor 22 of the sensor failure. In one

20 embodiment, microprocessor 22 also controls current sources I_2 and I_3 and selectively couples them to terminals 2 and 3, respectively, during a diagnostic cycle.

Latch 66 is connected to the output of

25 exclusive OR gate 64 and is used to latch the output of exclusive OR gate 64. For example, if the open sensor or open sensor lead is a momentary "glitch" which occurs during a period which is less than the sampling period of analog-to-digital converter 28, the sensor failure

30 signal provided by gate 64 is latched in latch 66 and provided to microprocessor 22. This signals microprocessor 22 that there was an open sensor condition during the sampling time period.

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Microprocessor 22 provides a reset signal to latch 66 which resets the output of latch 66.

Figure 2 is a flow chart 100 showing operation of microprocessor 22 in the embodiment of Figure 1A.

5   Operation of microprocessor 22 is in accordance with instructions stored in memory 30. Microprocessor 22 recalls R_{REFNOM} from memory 30 at flow chart block 102. At block 104, microprocessor 22 controls switch 62 to connect the non-inverting input of comparator 60 to the

10 voltage reference V_{REF1}. Next, microprocessor 22 provides a high input to exclusive OR gate 64. Microprocessor 22 controls multiplexer 20 to connect terminals 2 and 3 of terminal block 14 to the inputs of differential amplifier 26 at flow chart block 108. This

15 allows measurement of V_{RINPUT}. At control block 110, microprocessor 22 resets latch 66. V_{RINPUT} is measured at block 112 by microprocessor 22 using analog-to-digital converter 28. After obtaining V_{RINPUT}, microprocessor 22 observes the output of latch 66 at block 114. A HIGH

20 output from latch 66 indicates that the voltage across terminals 2 and 3 of terminal block 14 exceeded a predetermined maximum determined by V_{REF1} during analog-to-digital conversion by converter 28. If latch 66 provides a HIGH output, control is passed to block 116,

25 otherwise control is passed to block 118 where the measurement of V_{RREF} begins. V_{REF2} is connected to comparator 60 by microprocessor 22 using switch 62. At block 120, a logic LOW is provided to an input of exclusive OR gate 64.

30 Next, at block 122, microprocessor 22 controls multiplexer 20 to measure V_{REF} which is the voltage across resistor 38. At block 124, latch 66 is reset by microprocessor 22 and microprocessor 22 reads V_{REF} from analog-to-digital converter 28 at block 126. After

reading V_{REF}, microprocessor 22 observes the output of latch 66 at block 128. If the latch output is HIGH, microprocessor 22 determines that an error has occurred and control is passed to block 116. If there is no

5   error, control moves to block 130 where R_{INPUT} is calculated in accordance with Equation 1. At block 132, R_{INPUT} is converted to temperature by means of an algorithm or a look-up table stored in memory 30 and its value is transmitted at block 134. Following

10   transmission, the process is repeated and control is returned to block 102. In a similar manner also, diagnostics are done periodically on leads 2 and 3 also using I_2 and I_3 currents. Typically, all leads are scanned every time a total sensor update occurs.

15   If the output of latch 66 indicates the occurrence of an error, control is passed to block 116. At block 116, the value obtained from analog-to-digital converter 28 is discarded. At block 136, microprocessor 22 transmits a signal over loop 11 using IO circuitry 24

20   which indicates the occurrence of an error. Control is then returned to block 102 and the process is repeated.

     A monitor in the control room can monitor operation of transmitter 10 and detect error signals sent from transmitter 10. If transmitter 10 is

25   repeatedly sending error signals, the monitor in the control room can use this information to alert an operator that there is an open sensor condition at transmitter 10. Additionally, if errors occur only periodically, the operator can be notified that there

30   may be an impending problem with the sensor in transmitter 10. Intermittent errors can also be latched in the microprocessor software to provide a continuous alarm.

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The loose sensor connection diagnostic for the embodiment of Figure 1B operates similar to that described above for Figure 1A, and Equations 2 and 3 are employed to determine temperature.

5   It will be recognized by those skilled in the art that the circuitry set forth in the present invention may be modified as appropriate. For example, multiple circuits could be employed to simultaneously detect if the output voltage is above or below certain 10   thresholds. Further, more than two voltage references may be used. In another example, the voltage reference could be controlled by the microprocessor using a digital-to-analog converter such that the microprocessor can independently select the voltage threshold.

15   Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention. For example, the 20   comparison circuit can be connected at any appropriate location, such as between the multiplexer and the differential amplifier.

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WHAT IS CLAIMED IS:

1.   A temperature transmitter in a process control
system, comprising:

          a temperature sensor sensing a temperature
                and providing a sensor output related to
                a sensed temperature;

          an A/D converter coupled to the sensor output
                providing a digitized output related to
                the sensor output;

          a microprocessor coupled to the digitized
                output which compensates and processes
                the digitized output and provides a
                temperature output; and

          comparison circuitry which compares the
                sensor output to a first threshold and
                provides an inhibit signal to the
                microprocessor if the sensor output is
                outside of the first threshold.

2.   The temperature transmitter of claim 1 wherein
the sensor output includes a plurality of sensor leads
which are individually coupled to the comparison
circuitry through a multiplexer.

3.   The temperature transmitter of claim 1 wherein
the comparison circuitry compares the sensor output to
a second threshold and provides the inhibit signal if
the sensor output is outside the first and second
thresholds.

4.   The temperature transmitter of claim 2
including a switch connected to the first and second
thresholds and an input to the comparison circuitry
connecting the first or second thresholds to the
comparison circuitry input in response to a control
signal from the microprocessor.

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5.   The temperature transmitter of claim 1 wherein
the microprocessor is coupled to the inhibit signal and
the inhibit signal inhibits the temperature output.

6.   The temperature transmitter of claim 1 wherein
the comparison circuitry has a faster response time than
a response time of the A/D converter.

7.   The temperature transmitter of claim 1 wherein
the comparison circuitry includes a polarity control
input for selectively inverting the inhibit output.

8.   The temperature transmitter of claim 7 wherein
the polarity control input is coupled to the
microprocessor.

9.   The temperature transmitter of claim 1
including output circuitry coupled to a two-wire process
control loop which transmits the temperature output on
the process control loop.

10.   The temperature transmitter of claim 1 wherein
the sensor is an RTD.

11.   The temperature transmitter of claim 1 wherein
the sensor is a thermocouple.

12.   The temperature transmitter of claim 1 wherein
the microprocessor is coupled to the inhibit signal and
responsively provides a diagnostic output.

13.   A method of measuring temperature of a process
in a process control system, comprising the steps of:

            obtaining   a   sensor   input   related   to
                temperature of the process;

            providing a digitized output related to the
                sensor output;

            compensating   the   digitized   output   and
                providing   a   compensated   output
                indicative   of   temperature   of   the
                process;

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comparing the first sensor input with a
    threshold; and

providing an error signal based upon the
    comparison.

14.   The method of claim 13 including inhibiting
the compensated output in response to the error signal.

15.   The method of claim 13 including:

comparing the sensor input with a second
    threshold; and

providing the error signal based upon the
    comparison with the second threshold.

16.   The method of claim 13 including adjusting the
first threshold based upon a type of sensor which
provides the sensor input.

17.   The method of claim 13 wherein the step of
comparing is faster than the step of providing the
digitized output.

18.   The method of claim 13 including transmitting
the compensated output over a two-wire process control
loop.

19.   The method of claim 13 including selectively
inverting the polarity of the error signal.

20.   The method of claim 13 wherein the sensor
input includes a plurality of sensor leads, the method
including individually comparing a sensor input from
each sensor lead with a threshold.

21.   The method of claim 13 including providing a
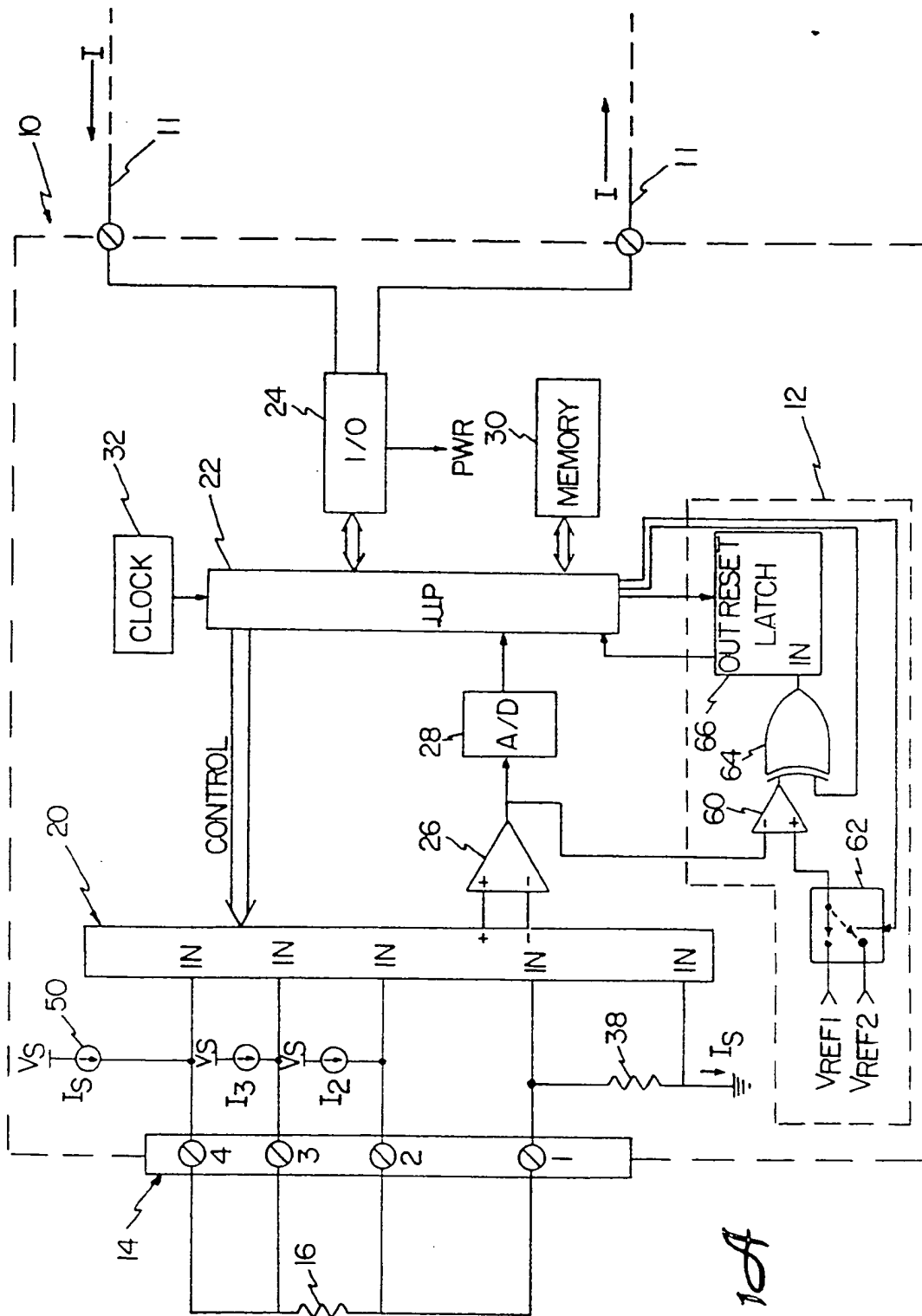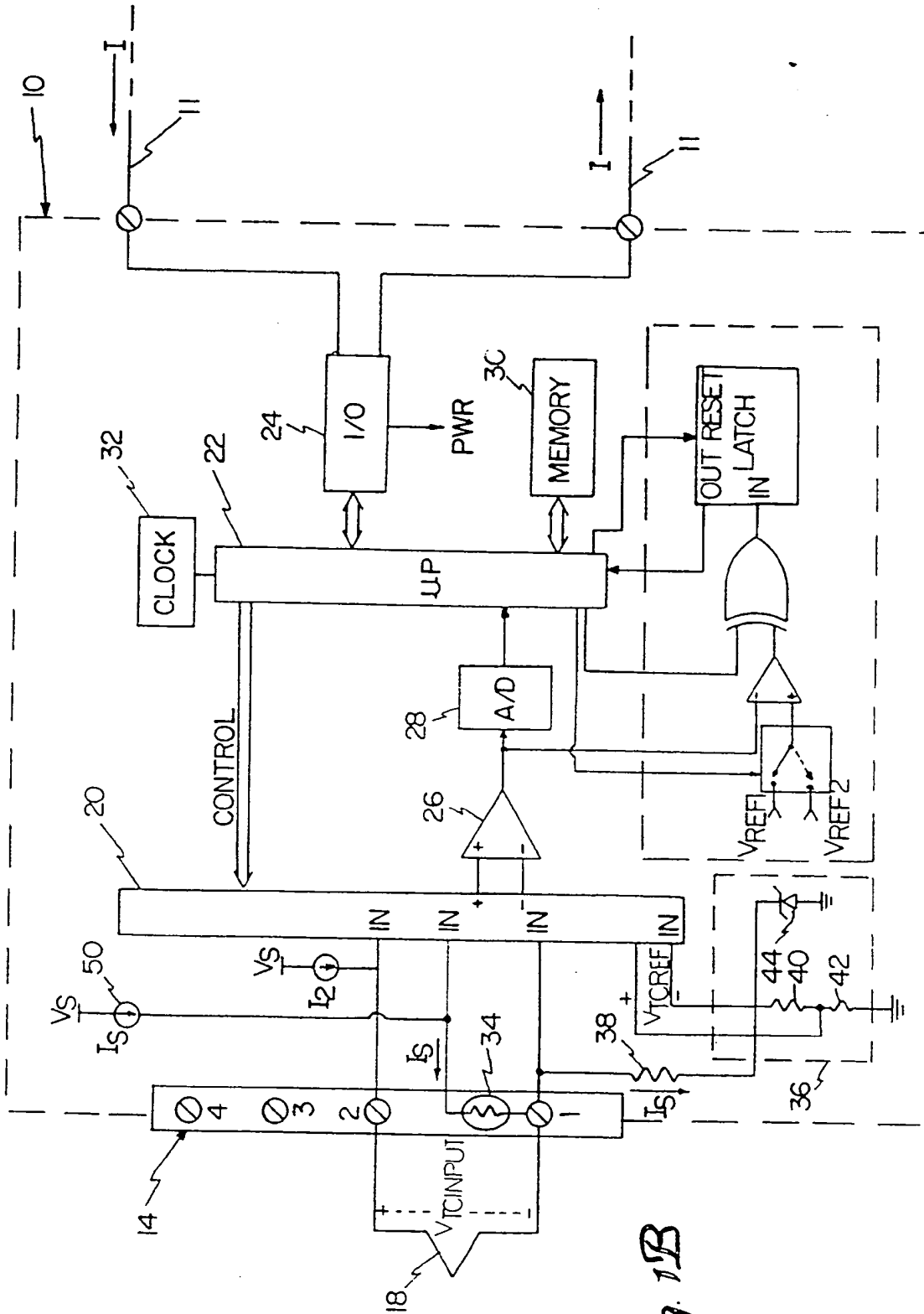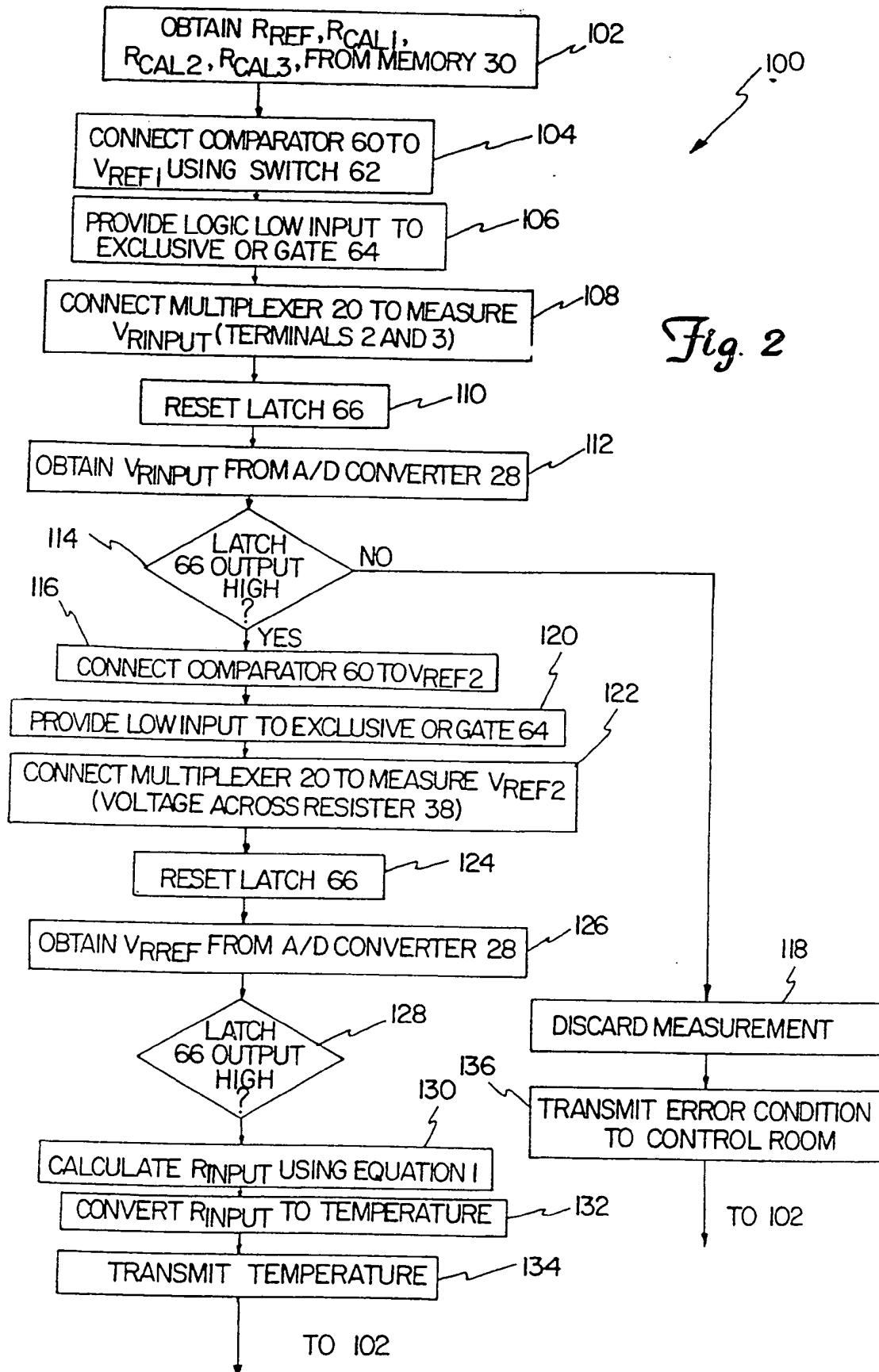diagnostic output in response to the error signal.

Fig. 1A

Fig. 1B

OBTAIN R_{REF}, R_{CAL1}, R_{CAL2}, R_{CAL3}, FROM MEMORY 30 — 102

100

CONNECT COMPARATOR 60 TO V_{REF1} USING SWITCH 62 — 104

PROVIDE LOGIC LOW INPUT TO EXCLUSIVE OR GATE 64 — 106

CONNECT MULTIPLEXER 20 TO MEASURE V_{RINPUT} (TERMINALS 2 AND 3) — 108

Fig. 2

RESET LATCH 66 — 110

OBTAIN V_{RINPUT} FROM A/D CONVERTER 28 — 112

114 — LATCH 66 OUTPUT HIGH? — NO

YES

116 — CONNECT COMPARATOR 60 TO V_{REF2}

120 — PROVIDE LOW INPUT TO EXCLUSIVE OR GATE 64

122 — CONNECT MULTIPLEXER 20 TO MEASURE V_{REF2} (VOLTAGE ACROSS RESISTER 38)

RESET LATCH 66 — 124

OBTAIN V_{RREF} FROM A/D CONVERTER 28 — 126

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DISCARD MEASUREMENT

128 — LATCH 66 OUTPUT HIGH?

130 136 — TRANSMIT ERROR CONDITION TO CONTROL ROOM

CALCULATE R_{INPUT} USING EQUATION 1

CONVERT R_{INPUT} TO TEMPERATURE — 132

TRANSMIT TEMPERATURE — 134

TO 102

TO 102

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   G01K7/02   G01K15/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   G01K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US,A,4 475 823 (STONE W PORTER) 9 October 1984 see column 3, line 50 - column 4, line 66 ---	1,10,12, 13,16
A	US,A,4 841 286 (KUMMER KARL T) 20 June 1989 see column 4, line 3 - line 63 ---	1,11-13, 16,21
A	US,A,4 279 151 (ANDERSON JACK A) 21 July 1981 see the whole document -----	1,9, 11-13, 16,18,21

☐ Further documents are listed in the continuation of box C.   ☒ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
22 August 1996	1 3. 09. 96

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl, Fax (+ 31-70) 340-3016	Ramboer, P

Form PCT/ISA/210 (second sheet) (July 1992)

Inter	nal Application No
	PCT/US 96/08839

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US-A-4841286	20-06-89	NONE	
US-A-4279151	21-07-81	NONE	